Changes in Mineralization with Aging-induced Transparency in Human Root Dentin

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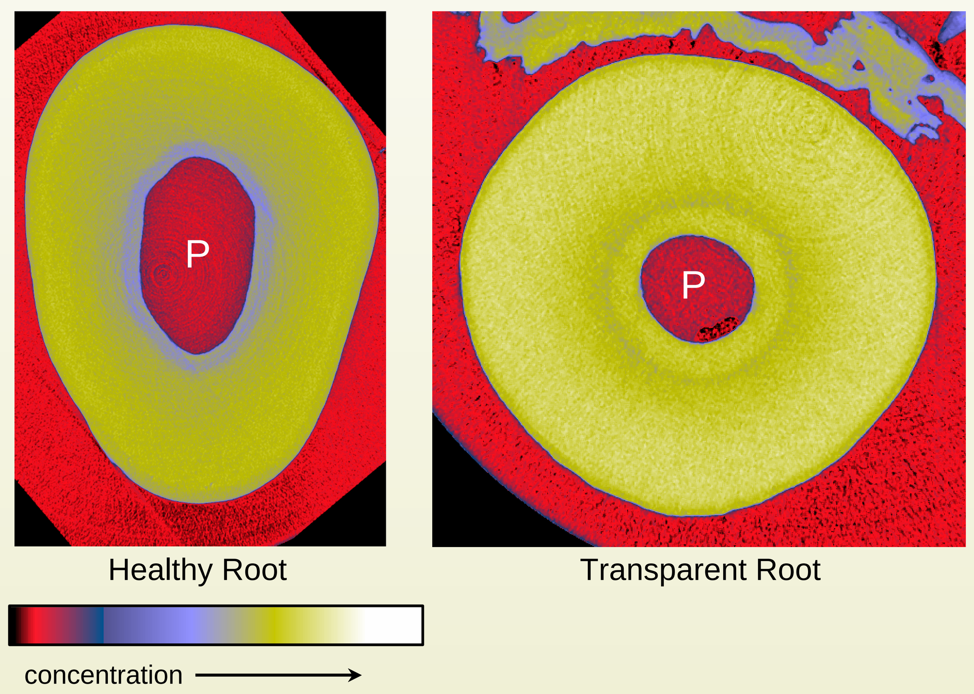
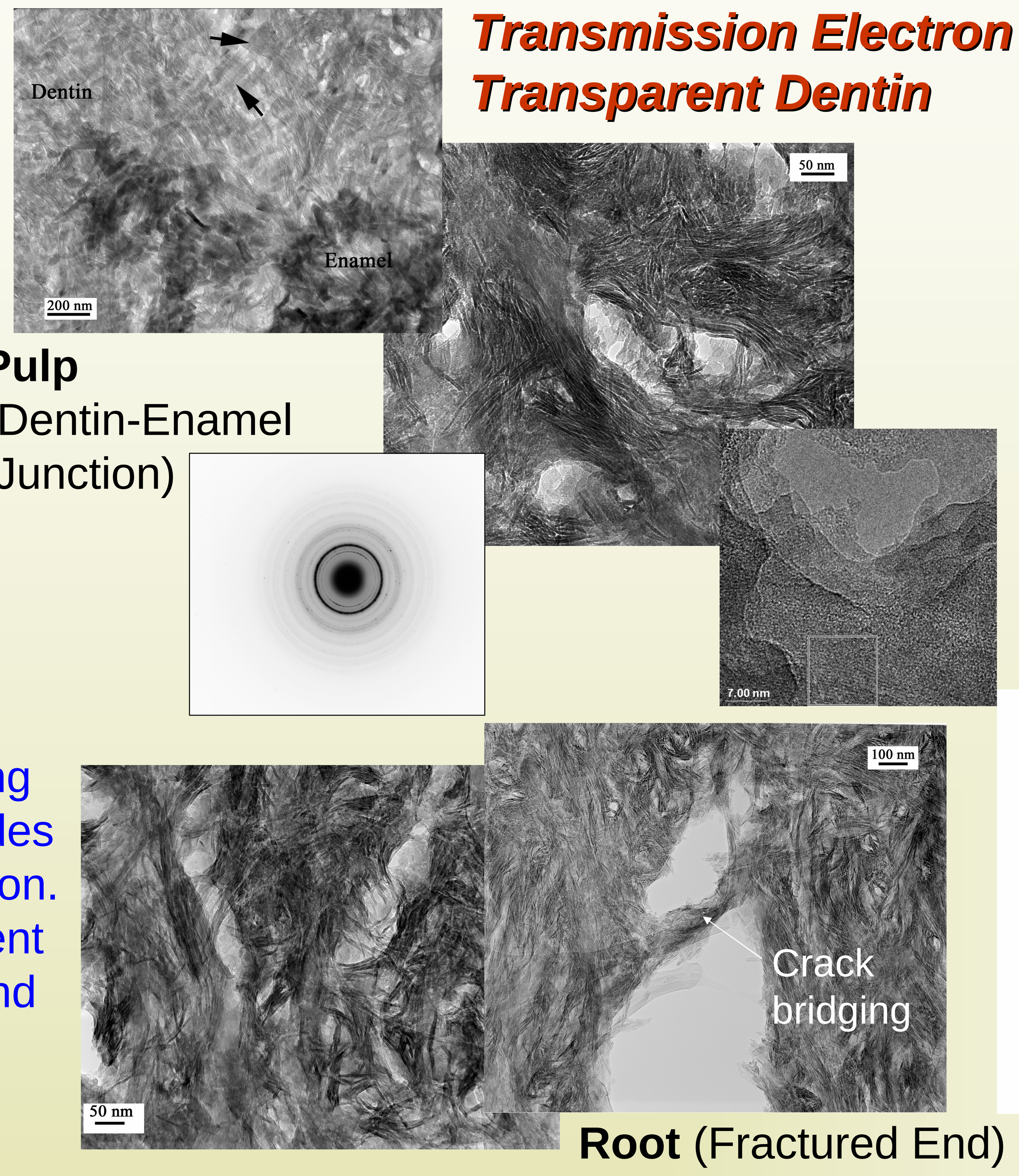
Despite substantial clinical interest in the mineralization and fracture resistance of human dentin, there is little information in the archival literature that looks at age-induced changes in such properties. Transparent dentin is often formed as a natural consequence of aging, and occurs when the tubule lumens (paths taken by the odontoblasts during dentinogenesis) become filled with mineral, decreasing the amount of light scattered off of the lumens. In the present study, we investigate these changes in mineralization and how they affect the mechanical properties.

X-ray Computed Tomography



X-ray attenuation coefficients from imaging using 25 keV synchrotron radiation provides a spatial mapping of the mineral distribution. Higher mineralization is seen in transparent dentin, especially close to the pulp (P), and is attributed to mineral accretion in the dentinal tubules.

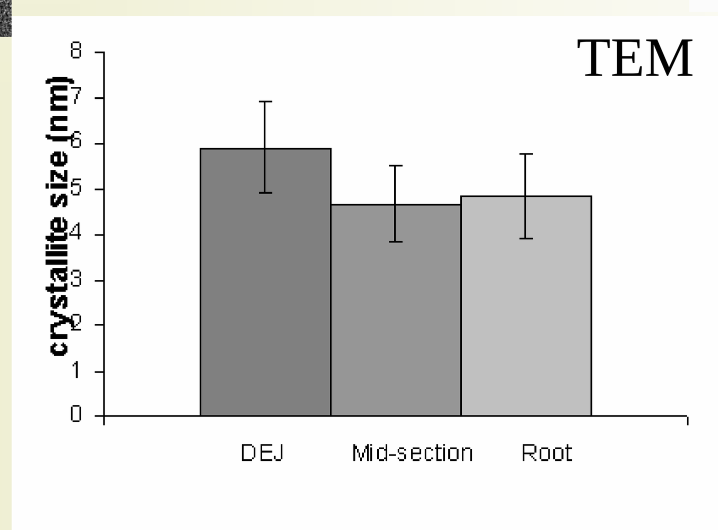
Transmission Electron Microscopy of Transparent Dentin



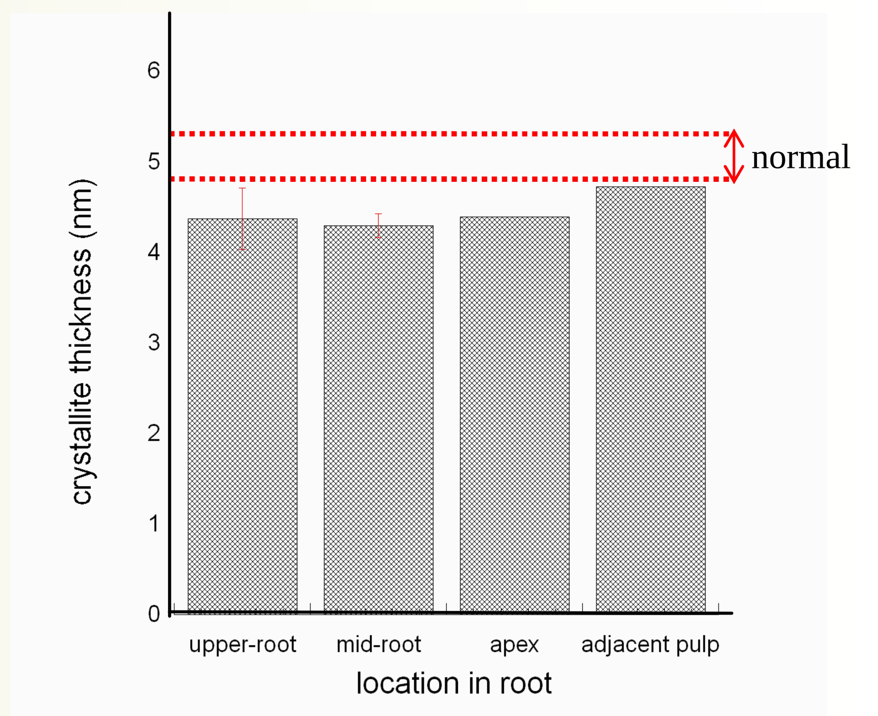
Pulp (Dentin-Enamel Junction)

Mid-section

Root (Fractured End)

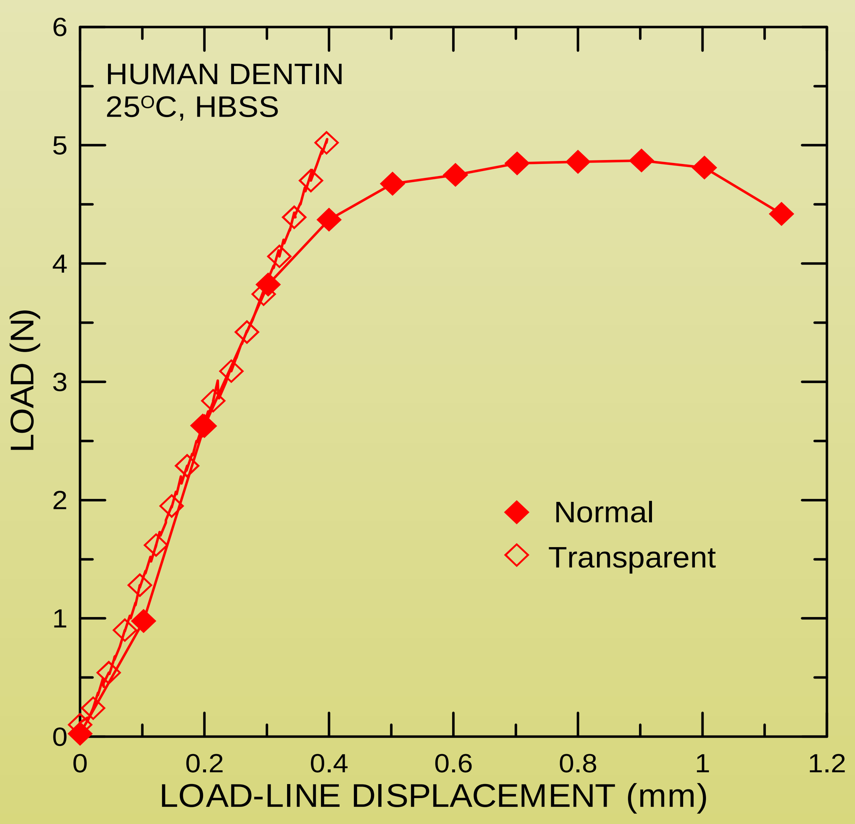


Small-Angle X-ray Scattering



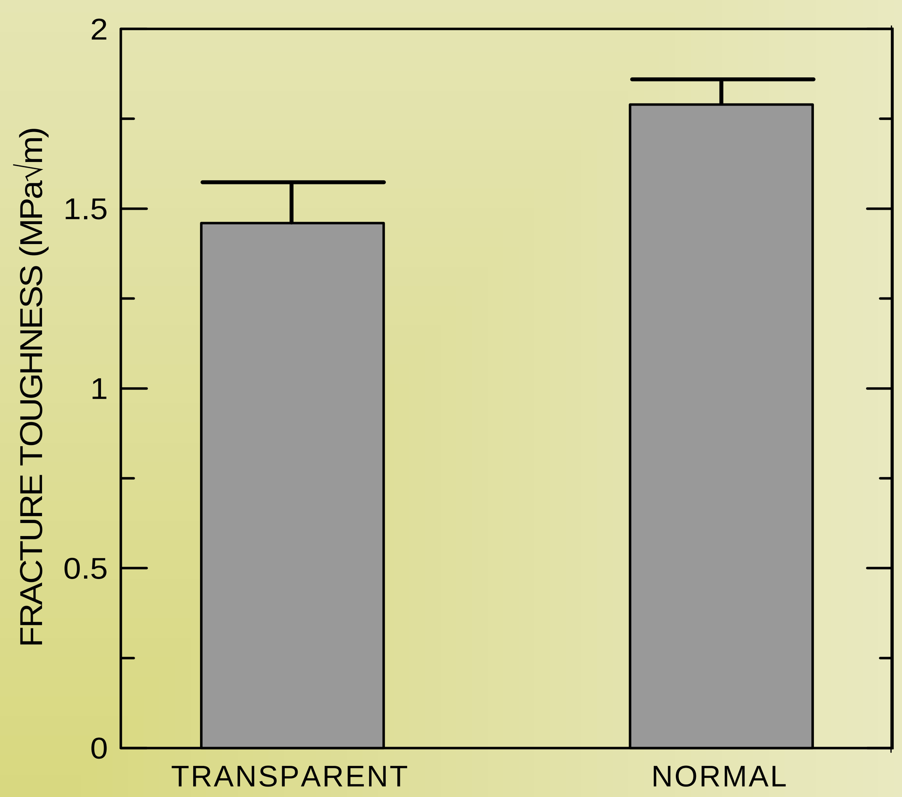
SAXS measurements using synchrotron radiation also suggested smaller intertubular mineral crystallite size, consistent with TEM observations.

Deformation Behavior



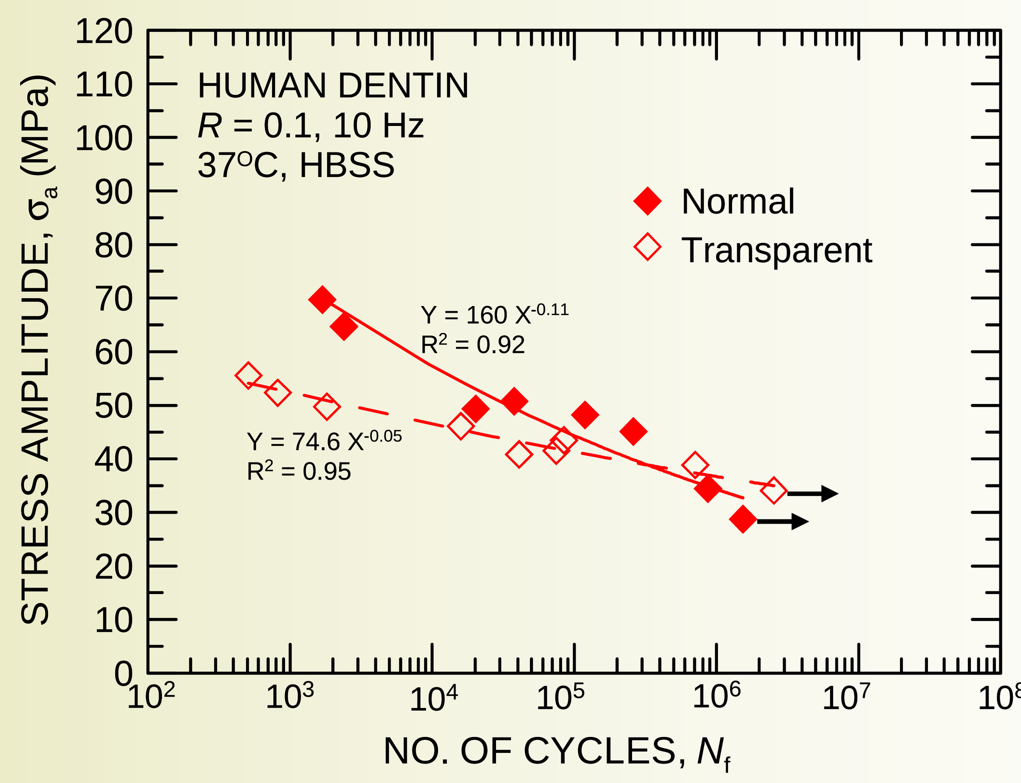
Macroscopic deformation behavior was studied using cantilever beam bending. Evidence of "yielding" and post-yield inelastic deformation is seen in normal dentin, but not in transparent dentin.

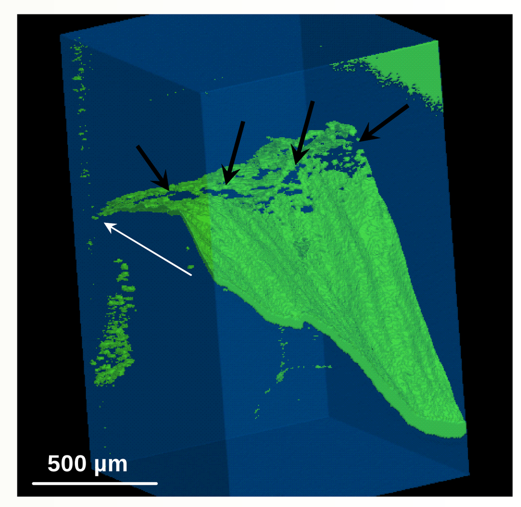
Fracture Toughness



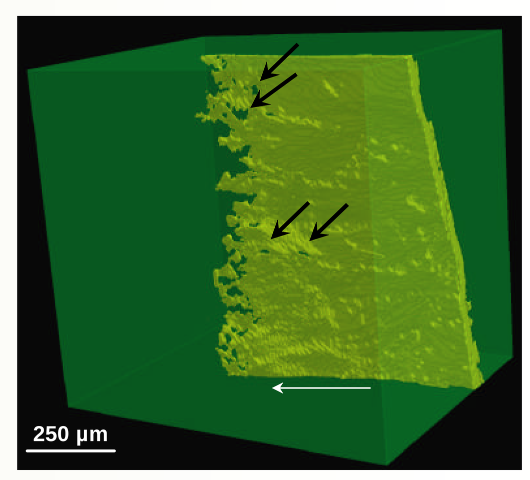
Fracture toughness was measured using three-point bend testing. Age-induced transparency lowers the fracture resistance of dentin by some 20%.

S/N Fatigue Behavior and X-ray Tomography





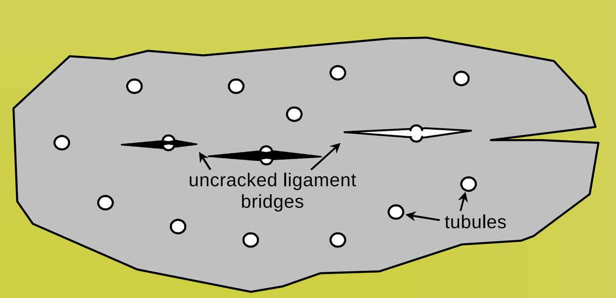
Normal



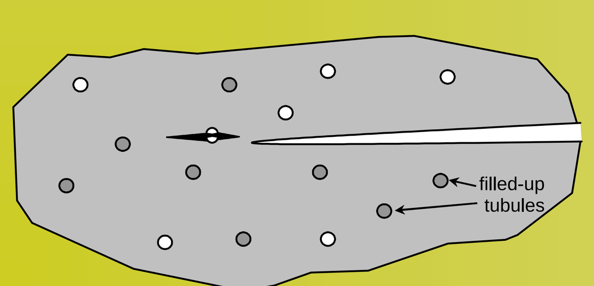
Transparent

Cantilever beam Stress-Life fatigue tests revealed that dentin shows "metal-like" fatigue behavior. Transparency affects low-cycle fatigue behavior. X-ray tomography showed evidence of "uncracked ligament" crack bridges in normal dentin.

Mineralization Changes Explain Differences in Mechanical Behavior



Normal



Transparent

Compared to normal dentin, transparent dentin has a lower toughness and much reduced "plasticity". Ageing induced changes in biomineralization lead to filling up of the tubules, presumably involving dissolution of mineral from the intertubular matrix, and re-precipitation into the tubules. Such changes lead to loss of "stress concentrations" in the dentin. This reduces microcrack nucleation at the tubule sites, and hence leads to poorer crack bridging. This explains the observed differences in the deformation behavior, fracture toughness and fatigue behavior.

Conclusions

- X-ray computed tomography revealed increased biomineralization in age-induced transparent dentin.
- Small-angle x-ray scattering and TEM revealed smaller intertubular mineral crystallite size and mineral accretion in tubules, suggesting a mechanism involving dissolution and re-precipitation.
- Mineralization changes could explain deterioration of deformation, fracture and fatigue properties with age-induced transparency.